# Searching for dark matter in X-rays: how *not* to check the dark matter origin of a spectral feature

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## ABSTRACT

In a recent preprint entitled *Searching for dark matter in X-rays: how to check the dark matter origin of a spectral feature* [arXiv:1001.0644], the authors have claimed that some archival X-ray data could be used to rule out dark matter in the form of 5-keV sterile neutrinos at the level of $20\sigma$. Unfortunately, the limit was derived incorrectly. We point out the shortcomings of this analysis and show that the tentative detection of a spectral feature consistent with a 5-keV sterile neutrino is not in contradiction with existing limits. Future observations of dwarf spheroidal galaxies will test this hypothesis.


Sterile neutrinos with masses of several keV can make up all or most of dark matter (Dodelson & Widrow 1994), can explain the observed velocities of pulsars (Kusenko & Segrè 1997; Fuller et al. 2003; Fryer & Kusenko 2006; Kusenko et al. 2008), and can play a role in the formation of the first stars and in other astrophysical phenomena (Biermann & Kusenko 2006; Kusenko 2009). The first dedicated search for relic sterile neutrinos using *Suzaku* (Loewenstein, Kusenko, & Biermann 2009) and *Chandra* (Loewenstein & Kusenko 2009) X-ray telescopes has produced some reliable new limits, as well as a tentative detection of a spectral feature consistent with a decay line of a 5 keV sterile neutrino.

However, Boyarsky et al. (2010) have claimed that this detection can be excluded at the level of $20\sigma$ based on the archival data from observations of M31. The X-ray data used by Boyarsky et al. (2010) are the same data that Watson et al. (2006) have used to produce an exclusion limit (which is not in disagreement with our result). Obviously, it would be quite remarkable if these archival data turned out to be better suited to search for sterile neutrinos than the ongoing and planned dedicated X-ray observations (Loewenstein & Kusenko 2009;


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Loewenstein, Kusenko, & Biermann 2009). We examine this claim, and we find it to be unfounded.

The strength of the expected signal depends on the amount of dark matter in the field of view. The strongest results of Boyarsky et al. (2010) were obtained based on the central region of M31. More specifically, they considered a ring with inner and outer radii of $5'$and $13'$ that correspond to 1.1 kpc and 3 kpc, respectively, at the distance of M31. To obtain the amount of dark matter in this part of their field of view, Boyarsky et al. (2010) considered several smooth profiles hypothesized in the literature, each of which gives a reasonable, but by no means unique, fit to the data. Of these profiles they chose the one that produces the lowest projected mass in this annulus, $1.1 \times 10^{10}\ M_{\odot}$, corresponding to a column mass density of 606 $M_{\odot}\mathrm{pc}^{-2}$. Their alleged exclusion limit is based on the assumption that at least this much of dark matter falls within the selected region of the field of view. If the amount of dark matter is lower by a factor of two or more, their claim is weakened or invalidated, as the expected signal-to-noise ratio decreases accordingly.

The problem with the analysis of Boyarsky et al. (2010) is that the smooth profiles they chose to consider do not represent the full range of uncertainty in the dark matter content in their field of view. The mass density in the central region of M31 is known to be dominated by baryonic matter. As emphasized by Klypin et al. (2002), a dark matter profile inferred from cold dark matter simulations is not applicable to the actual dark matter distribution in the central 3 kpc of M31, because the interactions of dark matter with baryons are expected to facilitate the angular momentum transfer and expulsion of dark matter from the central region. The presence of a rotating bar in M31 implies that the central density of dark matter should be sufficiently small to avoid causing the dynamical friction that would interfere with the rotating bar (Weinberg 1985; Debattista & Sellwood 2000). The spherical profiles may be incorrect for fitting the data because the dark matter distribution in the central region can be triaxial (Häfner et al. 2000). Finally, sterile neutrinos have different clustering properties on small scales from those of cold dark matter (Petraki 2008; Boyanovsky 2008a,b; Boyarsky et al. 2009), and there are no reliable calculations of dark matter profiles that take into account both the free-streaming of warm dark matter and the effects of the baryons.

Even aside from all of these caveats, the simplest spherical profiles giving the best fit to observational data require much less dark matter in the relevant region than what was claimed by Boyarsky et al. (2010), who fail to consider some of the most recent work on the mass distribution in M31. The baryonic mass, which dominates in the center of M31, itself is composed of (at least) two (bulge and disk) components with distinct mass-to-light (M/L) ratios that are not known *a priori*, but must be estimated from optical spectra under various simplifying assumptions about their respective stellar populations. Chemin,

Carignan, & Foster (2009) present models that include stellar mass-to-light ratios based on stellar population synthesis models that have average column mass densities in the 1.1-3 kpc annulus $\sim$ 1.5 times lower than the "minimum" value in Boyarsky et al. (2010) (while noting the lack of axisymmetry in the inner regions and presence of a central velocity dip in the HI rotation curve, and stating that that all their models "fail to reproduce the the exact shape of the rotation curve"). A new analysis of M31 based on the recent deep, full-disk 21-cm imaging survey (Corbelli et al. 2009) shows that the best-fit profile is achieved using the Burkert (1995) parametrization with the scale parameter $R_B = 77$ kpc (for which $\chi^2 = 0.81$ indicates a good fit to the data). For this profile, we obtain $3.4 \times 10^9\ M_\odot$ for the total projected dark matter mass in the $5'$-$13'$ region of M31. When Corbelli et al. (2009) impose a constraint on the virial mass of M31, their best fit corresponds to $R_B = 28$ kpc, in which case we obtain $2.9 \times 10^9\ M_\odot$ for the total projected dark matter mass in this region, corresponding to a column density of 128 $M_\odot \mathrm{pc}^{-2}$. In reality, the dark matter content of the region in question could be even smaller than the value obtained from the best-fit profile. In these models, the stellar mass-to-light ratios are higher than in Chemin, Carignan, & Foster (2009); and indeed, a recent study (Saglia et al. 2010) supports such a higher M/L in the bulge that dominates the stellar mass in the central regions. The M31 rotation curve is clearly consistent with a dark matter mass and column density that are factor $> 4$ below what Boyarsky et al. (2010) have claimed to be the minimal mass and the minimal density.

Since the minimal dark matter mass in the region chosen by Boyarsky et al. (2010) is at least 4 times smaller than the value they have assumed, the expected minimal intensity of the decay line should be scaled down by at least a factor of 4. Such a properly scaled feature falls well below the Galactic and Cosmic X-ray backgrounds, and it is completely swamped by the noise, making impossible the derivation of any robust exclusion limit. At these levels, unresolved hard X-ray emission from low-mass X-ray binaries and other stellar (and possibly interstellar) sources come into play (Bogdan & Gilfanov 2008), which may complicate the expected shape of the $> 2$ keV continuum. These additional components are completely absent in the ultra-faint dwarf spheroidals (Loewenstein, Kusenko, & Biermann 2009), such as Willman 1. Unlike the case of M31, dark matter predominates in these systems, and the dark matter distribution is fully determined by kinematics without the uncertainties introduced by the presence of multiple mass components.

For the reasons stated above, M31 is not as good a target for future observations as dwarf spheroidal galaxies. The ongoing and planned observations of dwarf spheroidal galaxies give the best opportunity to confirm or rule out 5 keV sterile neutrinos as a dark matter candidate.

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